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On-Site Incineration:

Overview of Superfund Operating Experience

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TABLE OF CONTENTS

FIGURES

TABLES

Table **Page**

INTRODUCTION

Incineration has been used as a remedy at more than 40 Superfund sites. Information on cost and performance of incineration can be valuable to remedial project managers (RPMs) and other decision makers responsible for future site cleanup projects. To date, reports on cost and performance for this technology have been limited.

Fifteen case studies were prepared to obtain additional data on operating experience for completed projects. These studies are published under a separate cover. The case studies are available on the Internet through the Federal Remediation Technologies Roundtable home page at http://www.frtr.gov under the topic "publications." The case studies are also available through EPA's CLU-IN homepage on the Internet at http://www.clu-in.com.

This report was prepared: 1) to summarize the case studies, 2) to provide technology descriptions under one cover, and 3) to make general observations based on individual applications. It includes an overview of incineration design, air pollution control systems, and regulatory requirements. General information on the selected sites is provided in Table 1. All tables cited in the text are presented at this end of this report. Summary tables include information on specific sites, corresponding to specific site case studies that will be published at a later date in a second report.

OVERVIEW OF ON-SITE INCINERATION TECHNOLOGY

Incineration uses controlled flame combustion to volatilize and destroy organic contaminants and is used to treat a variety of media, including soils, sludges, liquids, and gases. An incinerator consists of a burner, which ignites the supplied fuel and combustibles in the waste feed in a combustion chamber. Efficiency of combustion depends on three main factors of the combustion chamber: temperature, residence time of the waste material in the combustion chamber, and turbulent mixing of the waste material. Thermal destruction of most organic compounds occurs at temperatures between 1,100°F and 1,200°F. The majority of hazardous waste incinerators are operated at temperatures that range from 1,200°F to 3,000°F in the burning zone. To achieve thermal destruction, residence time usually ranges from 30 to 90 minutes for solid waste and 0.5 to 2.0 seconds for liquid waste. Turbulent mixing is important because the waste and fuel must contact the combustion gases if complete combustion is to occur. Sufficient oxygen must be present and is supplied as ambient air or as pure oxygen through an injection system [4].

A typical incineration systems consists of several distinct units. The first unit is the kiln or primary combustion chamber, into which waste is fed and in which initial volatilization and destruction of contaminants takes place. In many incineration systems, gases formed during incineration in the kiln include uncombusted organics or combustion by-products, referred to as products of incomplete combustion (PIC). The PICs are drawn to a secondary combustion chamber (SCC) designed to increase the efficiency of destruction of PICs or to incinerate a liquid feed stream. Residual bottom ash produced during the incineration process typically exits the kiln through a gravity drop and is then cooled before subsequent management.

From the SCC, the off-gas is routed through an air pollution control system (APCS), which may include a variety of units, depending on the types of contaminant being treated, the concentrations of those contaminants in the waste feed, and the design of the kiln. The APCS cools the off-gas and removes particulates or acid gases produced during the incineration process [3]. Gases are drawn through the incineration system by an induced-draft fan, which maintains a negative pressure within the system. A negative pressure reduces the potential that fugitive emissions will be produced and draws gases through the system at a specified flow rate to promote efficient destruction and removal of contaminants. Particulate matter collected in the APCS is removed periodically for subsequent management. Treated exhaust gas exits the system through a stack.

On-site incinerators are usually transported to sites by rail or flatbed truck. Such systems are prefabricated, transported to the site in pieces, and assembled on site. The size of mobile, on-site incinerators usually is restricted by the capacity of the transport vehicles. The maximum outside diameter of the mobile kilns observed for these case studies was approximately 14 feet.

INCINERATOR DESIGNS

Two primary incinerator types were evaluated in the case studies: rotary kiln incinerators and liquid injection incinerators. A third design, an infrared incinerator, was used at the Rose Township Dump site. However, this design is no longer used commercially in this country (please refer to the case study of that site for more information). The following subsections discuss rotary kiln incinerators and liquid injection incinerators. The designs are discussed in more detail in the case studies along with cost and performance data for each application.

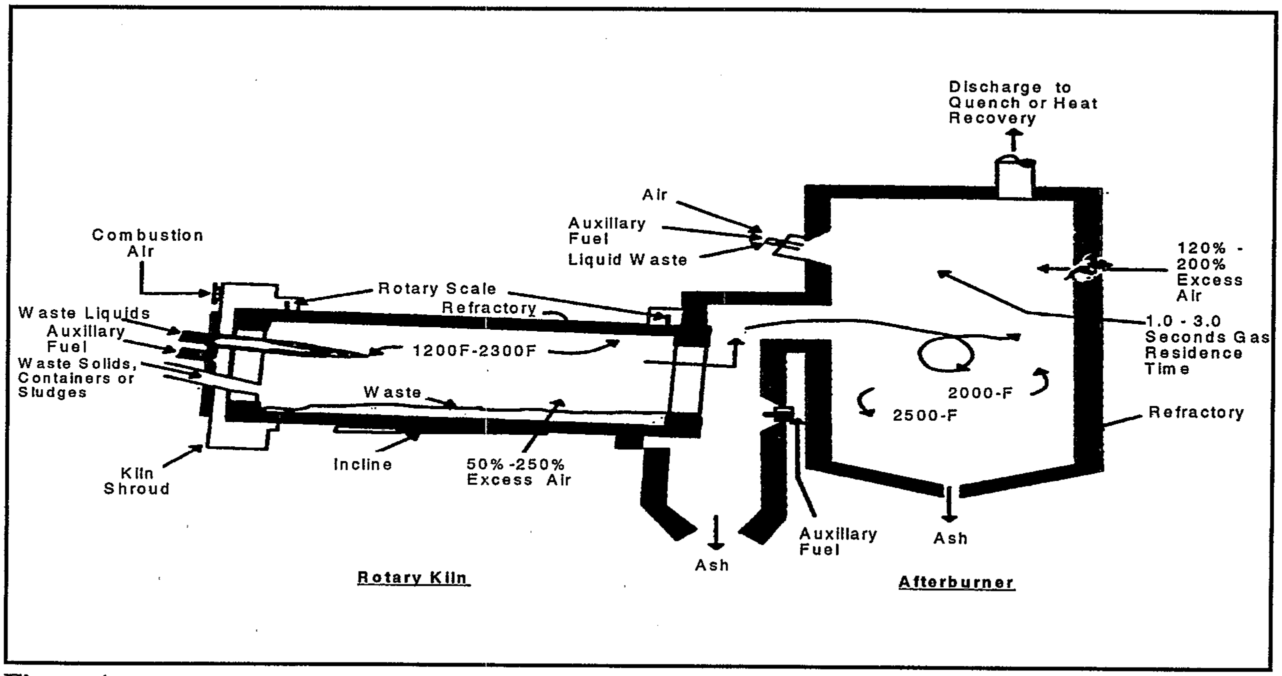

Figure 1 : Typical Rotary Kiln Incinerator (adapted from EPA-530-R-94-014)

Rotary Kiln Incinerators

Rotary kilns were used at 12 case study sites. The rotary kilns were used to treat most forms of waste, including solids, liquids, sludges, and debris. Figure 1 is a schematic diagram of a typical system.

Rotary kilns are cylindrical, refractory-lined steel shells supported by two or more steel trundles that ride on rollers, allowing the kiln to rotate on its horizontal axis. The refractory lining is resistant to corrosion from the acid gases generated during the incineration process [4]. The kilns in the case studies ranged from 6 to 14 feet in diameter and 25 to 110 feet in length. The burners for the kilns ranged from 10 million British thermal units (BTU) per hour to 120 million BTU per hour.

Rotation rate of the kiln and residence time for solids are inversely related; as the rotation rate increases, residence time for solids decreases [4]. Residence time for the waste feeds in the case studies varied from 30 to 80 minutes, and the kiln rotation rate ranged from 30 to 120 revolutions per hour. Another factor that has an effect on residence time is the orientation of the kiln [4]. Kilns are oriented on a slight incline, a position referred to as the rake. The rake typically is inclined from 2° to 4° from the horizontal.

Rotary kiln incinerators are designed with either a co-current or a countercurrent chamber. In the countercurrent design, waste is introduced at the end opposite the burner and flows down the rake toward the burner, while combustion gases are drawn up the rake. In a co-current design, the waste feed is introduced at the burner end and flows down the rake, while the combustion gases are also drawn down the rake. Most rotary kiln incinerators in the case studies were of the co-current design, which provides for more rapid ignition of the waste feed and greater gas residence time for combustion than does the countercurrent design [4].

Wastes are fed directly into the rotary kiln, either continuously or semicontinuously. Solids can be fed by such devices as ram feeders, auger screw feeders, or belt feeders. Liquid wastes can be injected with steam or by atomizing nozzles directly into the kiln through the main burner. Liquid wastes can also be injected by a waste lance or mixed with solid wastes [4].

The rotary kilns in the case studies were equipped with a secondary combustion chamber (SCC) (afterburner) to facilitate more efficient destruction of volatile organic contaminants. An SCC is a steel shell lined with refractory material and equipped with a burner. The SCCs included in the case studies have outside diameters ranging from 7 feet to 12 feet and lengths ranging from 30 feet to 38 feet. Off-gas from the kiln is routed through the SCC and typically has a residence time of 1 to 3 seconds. The SCC typically will operate at a higher temperature than the kiln. In the SCCs included in the case studies, the typical operating temperature ranged from 1,700°F to 2,000°F.

For one case study (the Sikes site), the design calculations showed that the incinerator optimal throughput could not be achieved because of the size of the SCC. A second SCC was installed in parallel with the first, increasing the throughput rate by 30 percent. This added cost was offset by the increased throughput rate, which reduced the length of time the incinerator was operated.

An oxygen-enhanced combustion system was used at one site to increase the efficiency of the rotary kiln. The combustion process is more efficient because the desired combustion efficiency is achieved at a lower residence time, thereby increasing throughput of waste. A potential drawback to the use of an oxygen-enhanced system is the possibility of generating higher concentrations of nitrogen oxide (NO_x) in emissions, compared with the concentrations in emissions generated by an unenhanced system.

Feeding of excessive quantities of highly combustible or explosive wastes to a rotary kiln may cause overpressurization. Sustained overpressurization may lead to releases of untreated gases to the environment through seals or other conduits. To avoid overpressurization in the kiln, incinerators first rely on an automatic waste feed cutoffs (AWFCO - to be discussed later) and then, if necessary, employ relief valves after the SCC. If an AWFCO does not quickly address the overpressurization event, such as an induced draft fan cutoff due to power failure, the relief valve is opened. The placement of the relief valve after the SCC allows for the maximum possible time for combustion gases to remain at high temperatures and, therefore, provides for the greatest possible destruction of pollutants.

During the activation of a relief valve, some combustion gases may escape untreated for a short period of time. The quantity of released combustion gases is small, however, because the airflow through the system rapidly decreases after the relief valve is opened. Recent risk analysis by the EPA indicates that risks to human health and the environment from the activation of relief valves are comparable to the already low risk from stack emissions during normal operations. Even with the small risk posed by activation of relief valves, some incinerators have installed an Environmentally Safe Temporary Emergency Relief System® (ESTER®). ESTER® is a relief valve that is equipped with a burner that thermally treats the vented gases.

Liquid Injection Incinerators

Liquid injection incinerators were used at two case study sites. These incinerators are used to treat combustible liquid and liquid-like waste, including sludges and slurries. A typical liquid injection incinerator consists of a waste burner feed system, an auxiliary fuel system, an air supply system, and a combustion chamber. Figure 2 is a schematic diagram of a typical liquid injection incinerator.

Liquid wastes were fed into the combustion chamber through waste burner nozzles, which atomized the waste and mixed it with air that ignited and burned in the combustion chamber. Typical residence time in the combustion chamber ranged from 0.5 second to 2 seconds, and the temperature of the combustion chamber ranged from 1,300°F to 3,000°F.

If the energy content of the waste is not high enough to maintain adequate ignition and incineration temperatures, a supplemental fuel, such as fuel oil or natural gas, may be pumped from a storage tank into the combustion chamber to augment the ignition potential of the waste mix. Air necessary for combustion is provided to the burner by a fan [5].

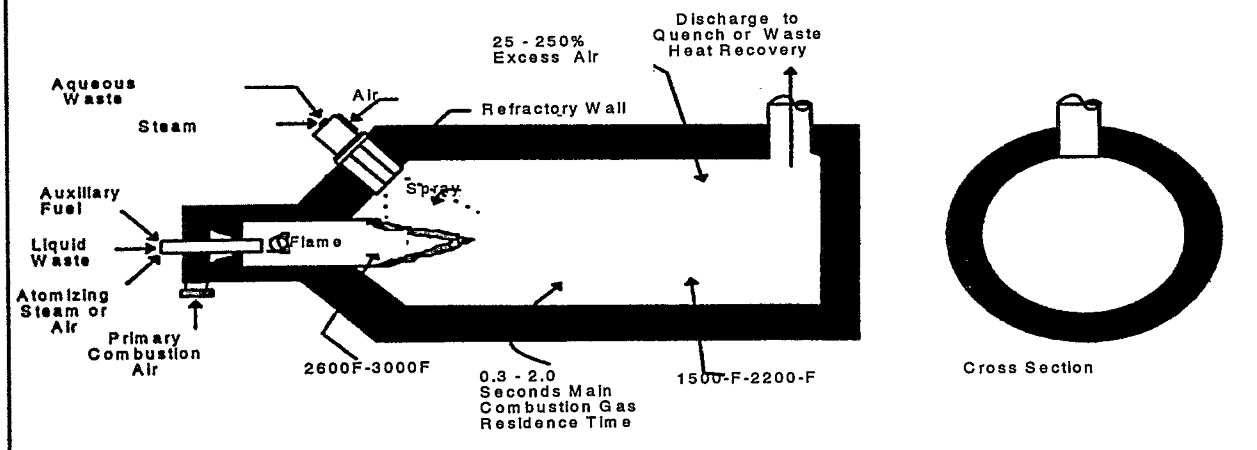

Figure 2: Typical Liquid Injection Incinerator (adapted from EPA-530-R-94-014)

Liquid injection incinerators are used to dispose of aqueous and nonaqueous wastes that can be atomized through a burner nozzle. Liquid wastes, sludges, or slurries that contain large amounts of solids must be filtered before they are stored in feed tanks that are usually pressurized with nitrogen. A control valve and flow meter are used to feed waste to the incinerator [5].

The combustion chamber for a liquid injection incinerator may be as simple as a cylinder lined with refractory material and can be oriented either vertically or horizontally. Liquid feed rate to the incinerator may be as high as 1,500 gallons per hour. Impingement of flames on the wall of the combustion chamber is undesirable because it can lead to corrosion of the refractory material and loss of heat; therefore, location of the burner is an important design criterion. Liquid injection incinerators also can use the oxygen-enhanced burners discussed in the section describing the rotary kiln, although none were encountered in the case studies [5].

A hybrid version of the liquid injection incinerator was used at one site, Rocky Mountain Arsenal. The submerged quench incineration system used a vertical downfired liquid incinerator. The liquid waste was injected at the top of the furnace into a gas flame. After incineration, the products of combustion were forced downward and cooled in a liquid quench tank. That process aided in washing out particulates and removing by-products from the exhaust gases. The high temperature in the incinerator melted noncombustible components, metals, and salts that had formed on the walls, so that those compounds flowed down the walls of the incinerator and cooled in the quench chamber [5].

AIR POLLUTION CONTROL SYSTEMS DESIGNS

APCSs are used on incinerators to control particulate matter and acid gas emissions. The APCS must be designed specifically for each incinerator, taking into consideration a number of factors including the incinerator type and operation as well as the waste stream to be incinerated and contaminants of concern. APCSs often include multiple components, operating in sequence, to effectively control emissions, which vary in physical and chemical properties.

In the various case studies, five components in different combinations made up the APCSs. The components were cyclone separators, gas conditioners (quench) systems, baghouses, scrubbers, and mist eliminators. A description of these unit operations, and observed and potential effects on incinerator cost and performance related to APCS designs, is provided below.

Cyclone Separators

Cyclones typically are conical or cylindrical chambers that stand vertically. Particles suspended in a gas stream usually enter the cyclone near the top and follow a spiral path along the wall of the chamber. The vortex causes particles to accelerate to the wall under centrifugal forces. The particles stay in the thin laminar layer of air next to the wall, and gravity pulls the particles down to a dust hopper at the bottom of the cyclone. The treated gas reverses direction near the bottom and rises through the central tube of the vortex to exit at the top. Periodically, dust is removed for subsequent management [2].

Cyclones can remove only particles that are 5 micrometers (μm) in diameter or larger. Efficiency in removing particles depends on the velocity of the gas, the rate at which the gas changes direction, and the size, distribution, density, and composition of the particles. Efficiency can be increased by increasing the swirling velocity of the gas, which is done by reducing the diameter of the cyclone chamber or increasing the flow rate of the gas [2].

Three of the incinerators in the case studies were equipped with cyclone separators to remove large particulates from off-gases. Cyclone separators operate at high temperatures and have no moving parts; they also operate at low cost and require little maintenance. Cyclones in the case studies were placed immediately downstream of the kiln or other combustion chamber. Figure 3 is a schematic diagram of a typical cyclone.

Gas Conditioners (Quench) Systems

Gas conditioners often are placed at the first stage of an APCS to enhance the performance of the components that follow. Gas conditioning operations may include use of a cooling fan, humidifying of the gas, and injection of reagents. The most common gas conditioner is the quench system, which was used in all of the incinerator systems in the case studies [2].

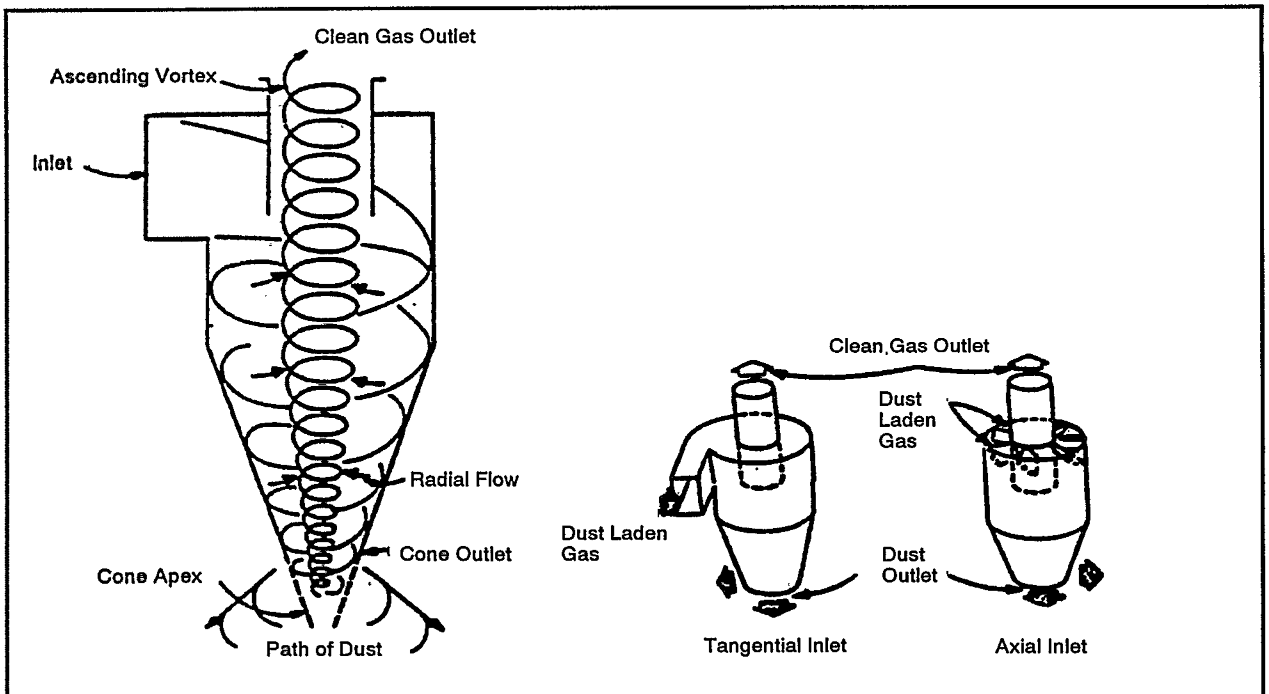

Figure 3: Typical Cyclone (adapted from EPA-530-R-94-014)

In a quench system, the gas enters the quench vessel and water is sprayed into the gas. The temperature of the gas falls as the water evaporates. To protect later components of the system that are sensitive to high temperatures, quench systems often are placed at the first stage of an APCS. In addition, if there is a potential to form dioxins and furans, the rapid cooling of gas in the APCS can minimize this potential by quickly lowering the temperature below the range that favors their formation. When that is the desired effect, the quench system immediately follows the SCC. Droplets of water and particles tend to adhere to the walls in the quench vessel; therefore, some quench systems use a film of water to wash particles from the wall. The wash water then collects at the bottom of the vessel [2].

Baghouses

Baghouses (or fabric filters) are used as part of the APCS to remove suspended particles from off-gases and were used at five of the case study incinerators. A baghouse consists of numerous filter bags made of a porous fabric on which dust particles collect and form a porous cake. Because this cake has the highest particulate collection efficiency, the efficiency of the filter is usually lowest at startup and after the bags have been cleaned. Off-gases entered the baghouse at relatively low temperatures, approximately 350 to 450°F. To prevent condensation that can plug and corrode the filter bags, the temperature must be within the range of temperature at which the fabric works most efficiently and above the dew point of water and common acid gases. The temperature also should be below any temperature in the range at which dioxins and furans can form.

Two common designs for baghouses are the reverse-air and the pulse-jet types, named for the cleaning systems they employ. Figure 4 is a schematic diagram of a typical reverse-air baghouse. Reverse-air baghouses have cylindrical bags into which the flue gas is directed. As the gas flows through the fabric, dust collects on the inside of the bags. Periodically, the air flow is reversed, causing dust cakes to fall from the bag to a hopper below. The cleaning procedure occurs at a low gas velocity, which does not subject the bags to excessive wear and tear. Pulse-jet baghouses also have cylindrical bags, but with an additional internal frame. The frame, called a cage, holds the bags while the gas flows from outside the bag through the fabric to the inside of the bag. The cleaning process for a pulse-jet baghouse tends to be more vigorous than that for the reversed-air baghouse; therefore, the lifetime of the pulse-jet bag is not as long. In both designs, the dust cakes are removed from the hoppers periodically for subsequent management [2].

The gas-to-cloth ratio is the ratio of the volumetric flow rate of the gas to the filter surface area and is expressed as the ratio of cubic feet of gas per minute passing through one square foot of cloth ($acfm/ft^2$). Pressure drop is an important measurement for a baghouse. A very high pressure drop may indicate that the bags are plugging or binding. Low pressure drops may indicate there are holes or leaks in the fibers [2].

Wet Scrubbers

Wet scrubbers are commonly used to remove particulate matter and soluble gases from the stack emissions. The designs observed in the case studies were venturi scrubbers to remove particulate matter, followed by packed-tower scrubbers to remove soluble gases.

Venturi scrubbers are a section of duct the diameter of which narrows and then widens, forming a throat (see Figure 5). At the sites that used venturi scrubbers, a recirculated liquid usually was injected into or just upstream of the throat. The gas accelerated in the throat, causing atomization of the liquid. In some systems, spray nozzles also were used to atomize the liquid on injection. The mixture of particles and droplets decelerates as it moves into the expansion section, and the droplets begin to aggregate. Gravity pulls some of the droplets out of the gas stream, and the mixture then passes through a mist eliminator that removes more droplets from the gas [2].

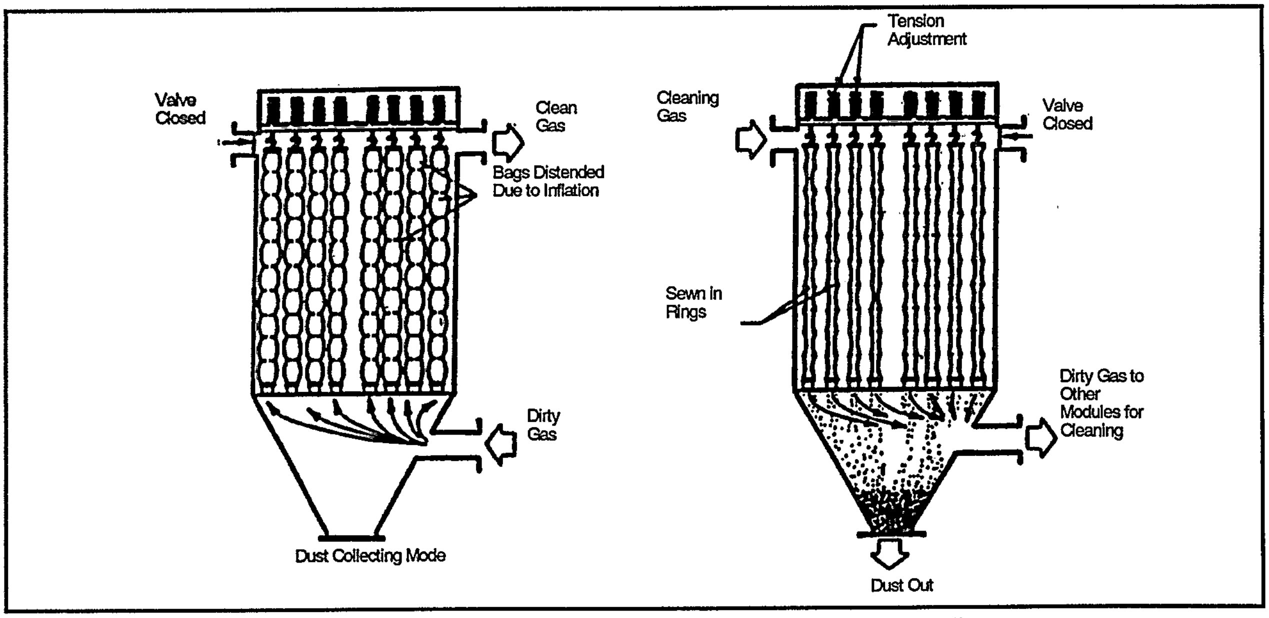

Figure 4: Typical Reverse-Air Baghouse (adapted from EPA-530-R-94-014)

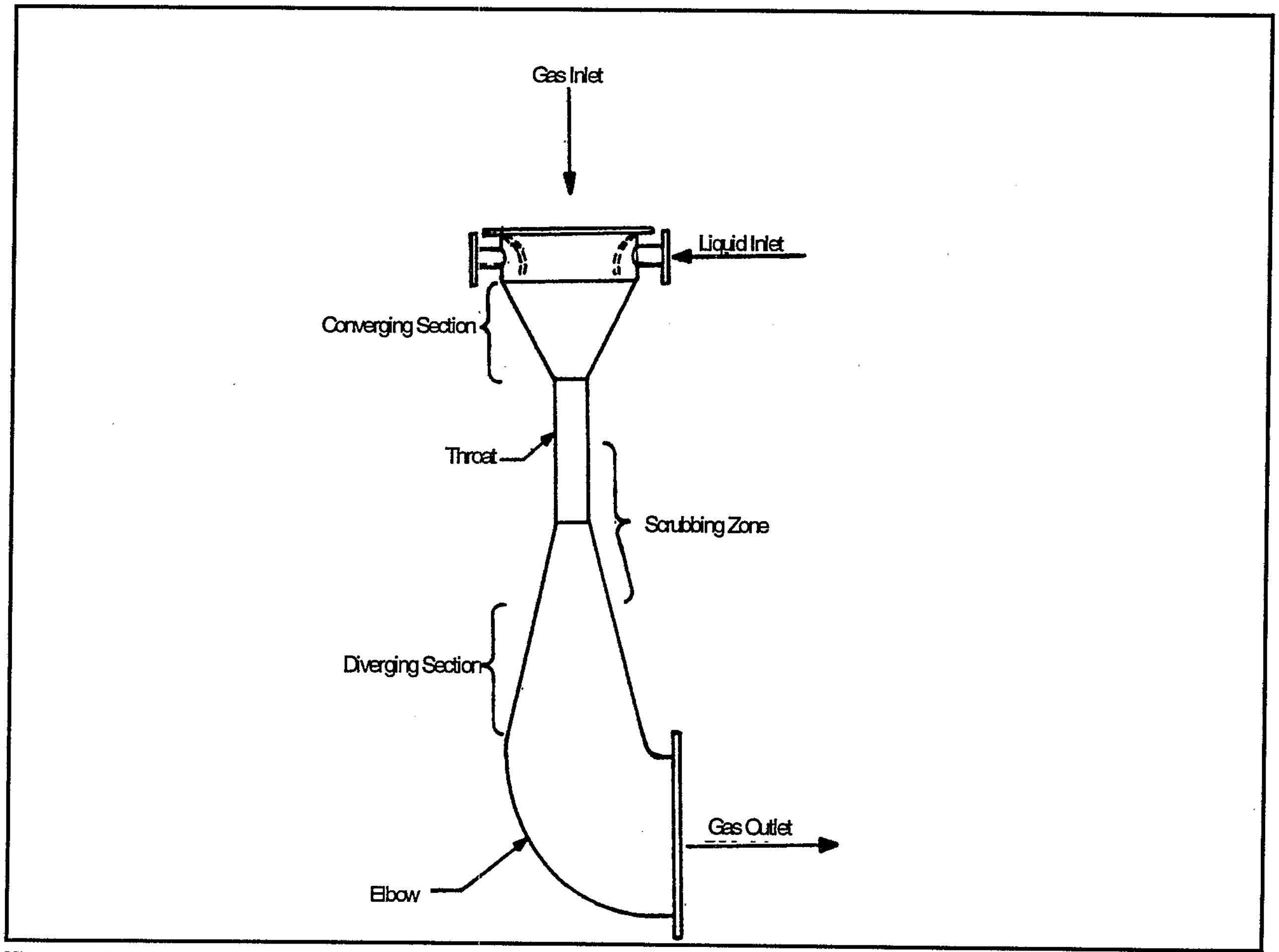

Figure 5: Typical Venturi Scrubber (adapted from Buonicore, A.J. and W.T. Davis, *Air Pollution Engineering Manual*, 1992)

In a packed tower scrubber, a bed of packing material, usually open plastic spheres, fills a section of the scrubber vessel. The gas stream enters at the base and flows up through the bed of packing material. The liquid enters at the top and flows down. The packing material increases the surface area that allows the gas to contact the liquid. The liquid collects at the bottom, and the gas exits near the top. The liquid is removed and can be treated in a number of ways [2].

Mist Eliminators

Fine droplets of liquid are removed using mist eliminators. Mist eliminators were used at five case study incinerators. In these systems, the mist eliminators always were located downstream from the scrubbers. Most of the mist eliminators in the case studies used wave plates or meshes of fine wire, designed to provide both a large surface area for collection of droplets and a high void space through which the gas flows. The droplets collided with the plates or wire and fell to the bottom of the structure, where they collected until removal for subsequent management. Mist eliminators usually are cleaned with a mixture of fresh water and recycled water.

PERFORMANCE OF ON-SITE INCINERATION

Based on available performance information, all 15 case study projects achieved their established performance standards. Performance standards for an incineration system are determined during a trial burn, when the system is operated at worst-case conditions, while still meeting applicable emissions limits (see Regulatory Requirements). Samples of the waste feed and measurements of emissions taken while the system is operated during such conditions then are used to determine the degree of destruction and removal of the constituents of concern. During the trial burn, which typically requires 2 to 5 days to complete, critical operating parameters are measured and then are used to establish values for the operating parameters for the post-trial burn operation of the system such as minimum combustion chamber pressure, maximum feed rate for each waste type, maximum carbon monoxide (CO) emissions, and various limitations for APCSs (for example, minimum pressure drop across a baghouse). During the operation of the incinerator, these parameters are monitored continuously to ensure that they remain within the limits set during the trial burn. It is assumed that operating the system within the range of all the acceptable operating limits will ensure that the incineration system meets the required performance standards.

During the trial burn, principal organic hazardous constituents (POHC) are used to measure the destruction and removal efficiency (DRE) of the incinerator (the detailed requirements for determining DRE are presented in regulations at Title 40 of the Code of Federal Regulations (40 CFR) 270.62). The POHCs are selected for each site to be representative of the waste burned at that site. The selected POHCs must be at least as difficult to destroy as the other contaminants of concern so that the destruction of the POHCs indicates adequate destruction and removal of all organic contaminants of concern. POHCs may be introduced, or spiked, into the waste and may be different than the actual contaminants if, for example, the concentrations of contaminants in the waste are hard to measure at the concentrations expected. During the trial burn, the concentration of POHCs in all influent streams and stack gas emissions is measured and used in conjunction with measurements of feed rate and stack gas flow rate to calculate the DRE. Table 2 presents available information on stack gas emissions measured during trial burns for the case study sites.

Performance - Automatic Waste Feed Cutoffs Systems

The incinerator system is equipped with an AWFCO system that immediately stops waste feed into the incinerator if any of the operating parameters are outside the acceptable ranges established during the trial burn. AWFCOs also are activated if concentrations of certain indicator contaminants in the exhaust gases exceed their respective limits. Those contaminants can include CO and total hydrocarbons (THC), which are indicators of incomplete combustion and are measured by continuous emissions monitors (CEMs), and hydrogen chloride (HCl) and free chlorine gas (Cl_2). AWFCOs help to ensure safe operation of an incinerator and allow the owner or operator to make adjustments to ensure that the incinerator is operating within its established operating range.

Information was requested from site owners or operators about the numbers of AWFCOs at each site and the cause of the cutoffs. Information about the frequency of AWFCOs was available for 5 of the 15 sites. The most frequent cause of AWFCOs identified by RPMs and other site managers was overpressurization of the kiln. For example, at the Times Beach site, overpressurization was a daily occurrence. In many cases, site managers identified excess moisture in the waste feed as the reason for the overpressurization. Other significant causes of AWFCOs included stack gas concentrations of oxygen (Vertac and Sikes sites) and concentrations of oxygen at the exit of the SCC (Old Midland site) that fell below the minimum acceptable concentrations. Possible causes of those AWFCOs include changes in the waste feed from that identified by the initial characterization. For example, if the concentration of organic compounds and the BTU value of a waste feed are higher than expected, the excess level of oxygen to ensure complete combustion decreases, triggering an AWFCO. Other comparatively frequent causes of AWFCOs included temperatures in the SCC that fell below acceptable limits (Old Midland site), feed rate above the maximum limit (Sikes site), and stack gas velocity that exceeded the maximum limit (Old Midland site).

Performance - Weather-Related

Weather affected the operation of several of the systems in the case studies. At the Yakima site, shakedown activities were scheduled during the winter, with average temperatures of 25 °F. The cold weather delayed startup activities, and the incinerator projects fell behind schedule. Power outages due to strong storms were problems at Times Beach and Bayou Bonfouca. At these sites, a decision was made to shut down the incinerators during storms. Finally, at the MOTCO site, heat caused electrical switchgear to overheat, cutting of the induced draft fan and resulting in a shutdown of the incinerator;

site personnel speculated that this event could have been avoided if the equipment had been located in an air-conditioned building.

MATRIX CHARACTERISTICS

In preparing the case studies, EPA collected information about matrix characteristics that affect cost or performance of incineration. Table 3 provides a summary of available information about matrix characteristics. Pretreatment was employed at the majority of the case study sites. Such pretreatment included crushing, milling, and mixing the waste with lime or sand to adjust the particle size, moisture content, or pH of the solids. Site personnel at the Old Midland site attributed a lack of problems with on-site incineration largely in part to thorough characterization of the wastes that were fed to the incinerator. Conversely, at some sites where the matrix characteristics had not been adequately characterized during the remedial investigation (RI) or other site investigation, incinerator operation was adversely impacted. For example, at the Bridgeport site, the waste feed was interrupted when drums and other debris encountered during the excavation of an on-site lagoon were fed to the incinerator and became entangled in the conveyer belt. In other cases, excess soil moisture and the presence of contaminants or matrices that had not been anticipated based on the results of site investigations resulted in problems with operation. At the MOTCO site, design and construction were based on information collected during the RI and feasibility study (FS). Severe slagging problems occurred when incineration began, either because of the presence of contaminants that had not been identified during the RI or because of the failure to define soil characteristics accurately. Disagreements about the performance of the incinerator led to court action and a suspension of remedial activities at the site.

At the Bridgeport site, overpressurization of the kiln caused several AWFCOs. Frequent overpressurization also occurred at Times Beach. Personnel working at the site attributed this to excess moisture in the soil and suggested excavating the soil when it was dry. When time constraints mandated excavation of moist soil, alternative methods, such as the addition of lime, were used to dry the soil.

At three sites, MOTCO, Bridgeport, and Sikes, slagging was encountered. Slagging was attributed to the presence of unacceptably high concentrations of inorganic contaminants or minerals in the waste feed. Slagging decreased throughput capacity as the internal diameter of the kiln was reduced by slag. At the Sikes site, a recirculating waterfall configuration at the bottom of the SCC was designed to catch and cool falling pieces of slag. The technique worked well for small pieces of slag, but larger pieces created large amounts of steam, which rose into the kiln and caused overpressurization.

Matrix characteristics affected operation of the incinerator at the Vertac site. At this site, the feed consisted of solid and liquid phases, and the heat content of the solid and liquid phases of waste differed. The variable heat content of the solid and liquid waste streams required continuous balancing of the volume of the two waste streams that were fed to the incinerator to maintain a constant temperature in the kiln. Another experience at Vertac was that the calcium hydroxide reacted with HCl, a by-product of the incineration at this site, creating calcium chloride residues which then clogged the spray drier. Sodium hydroxide, which did not cause clogging, was then used as the neutralizing agent.

COSTS OF ON-SITE INCINERATION

Cost information was obtained for 13 of the 15 sites included in the case studies. The level of detail of cost information varied from site to site. Detailed breakdowns of costs were available for 7 of the 15 sites. At those sites, the costs of treatment -- excluding before- and after-treatment costs -- ranged from $120 to $1,350 per ton. Many of the sites where detailed information was not available were operated by potentially responsible parties (PRPs).

Table 4 presents a summary of the available cost data for the case study sites. Treatment costs were calculated on a unit-basis when data on the cost for treatment-only were available. Where detailed costs were not available, total costs of the site cleanup are given.

COMMUNITY INVOLVEMENT

Community involvement in the case study projects varied both in terms of the level of involvement and the numbers and type of issues raised. Key issues included concern that the on-site incinerators, which had been built for the purpose of remediating the site, would become a permanent facility and be used to treat off-site wastes; concern over noise; and concern about emissions from the incinerator. At some sites, citizens were generally supportive of the project. Examples of community involvement for the case study projects are provided below.

At the Times Beach site, many citizens voiced concern that the incinerator would begin incinerating waste from sites outside the state. Citizens near the Sikes site also expressed concern that the incinerator would become permanent. Before incineration began at either site, residents in the vicinity of the Rose Disposal Pit site and the Times Beach site expressed concern that noise might disturb the community. At Times Beach, most activities took place inside buildings, and officials at the Rose Disposal Pit site worked with local officials to limit any effects of the project on the community; therefore, the local community at each site did not perceive noise as a problem. At the Bayou Bonfouca site, which is in a residential area, members of the local community identified noise as an issue. A silencing system installed on the stack and an induced-draft fan was used to allow 24-hour operation of the incinerator without disturbing residents. At the Vertac site, incineration was halted when community groups, Greenpeace and the Government Accountability Project, concerned about the incineration of wastes containing dioxins obtained restraining orders.

REGULATORY REQUIREMENTS

On-site incineration selected as part of a remedy under the Comprehensive Environmental Recovery, Conservation, and Liability Act (CERCLA) must comply with applicable or relevant and appropriate requirements (ARARs) (see section 121 of CERCLA). These ARARs include federal, state, and local regulations. A discussion of several relevant federal regulations is provided below.

Because much of the waste that is incinerated at Superfund sites is defined as hazardous waste, there are several potential ARARs under the Resource Conservation and Recovery Act (RCRA). Incinerators at Superfund sites that burn hazardous wastes must meet the RCRA incinerator regulations (40 CFR parts 264 and 265, subpart O). Incinerator performance standards include:

- At least 99.99 DRE for principal organic hazardous constituents
- At least 99.9999 percent DRE for wastes that contain dioxins and furans
- Less than 0.08 grains per dry standard cubic foot (gr/dscf) of particulate matter (PM)
- Less than 4 pounds per hour HCl or less than 1 percent of HCl in the stack gas

On-site incinerators that are used to dispose of polychlorinated biphenyls (PCBs) may also be subject to the requirements under the Toxic Substances Control Act (TSCA) set forth in 40 CFR part 761. The regulations require that wastes that contain more than 50 milligrams per kilogram (mg/kg) of PCB and that are incinerated meet a DRE of 99.9999 percent. Compliance with this DRE is determined as it is under RCRA regulations.

Ash or other residues that are generated by incineration are subject to the RCRA Subtitle C requirements if they are determined to be hazardous wastes under 40 CFR part 261. Any RCRA hazardous waste is also subject to the land disposal restrictions under 40 CFR part 268.

Wastewaters generated by on-site incineration (for example, scrubber water) and discharged to waters of the U.S. must comply with ARARs under the Clean Water Act. Standards for the discharge of process wastewater from incinerators include:

- Requirements of the National Pollutant Discharge Elimination System, which regulates the amount of contaminants discharged directly to a surface-water body (40 CFR parts 122 and 125)
- Requirements for standards for pretreatment that regulate the amount of contaminants discharged to a publicly owned treatment works (40 CFR part 403)

Residuals Management

At three sites, residues were required to be managed as hazardous waste. At the Vertac and Rocky Mountain Arsenal sites, the waste feed was a listed hazardous waste, and, therefore, residuals, such as ash, salts, and scrubber water, were hazardous waste. At Bridgeport, the metals present in the ash caused the ash to fail analysis by the toxicity characteristic leaching procedure (TCLP); the ash, therefore, required stabilization and disposal off site in a landfill permitted under RCRA Subtitle C. At those three sites, the unit costs were higher than for the other sites evaluated. At most of the sites, however, ash was landfilled on site after analysis by TCLP. Most of the liquid waste was treated at an on-site wastewater treatment system and subsequently discharged to surface water.

Guidance

In addition to the regulations listed above, EPA has developed several guidance manuals to assist federal and state government officials and the regulated community in assessing the performance of incineration. Although the guidelines in these manuals are not ARARs, they may assist RPMs or decision makers in interpreting compliance with ARARs or provide technical clarification of the intent of ARARs. The guidance manuals include:

- EPA. 1991. Implementation Document for Boiler and Industrial Furnace Regulations. November.

- EPA. 1990. Quality Assurance/Quality Control (QA/QC) Procedures for Hazardous Waste Incineration. EPA/625/6-89/023. January.
- EPA. 1989. Hazardous Waste Incineration Measurement Guidance Manual. Center for Environmental Research Information. EPA/625/6-89/021. June.
- U.S. Environmental Protection Agency (EPA). 1989. Guidance on Setting Permit Conditions and Reporting Trial Burn Results. Office of Solid Waste and Emergency Response. EPA/625/6-89/019. January.

Proposed Regulations

At the time this document was published, EPA had proposed revised regulations applicable to hazardous waste combustion (HWC) devices, specifically incinerators and cement kilns and light-weight aggregate kilns that treat hazardous wastes. The maximum achievable control technology (MACT) approach defined in Title 3 of the 1990 Clean Air Act Amendments is being applied in the development of the new emissions standards. The proposed rule specifically includes "devices [that] consist of mobile units (such as those used for site remediation and Superfund clean-ups)." [4]

The pollutants for which emission standards are proposed under the MACT rule are:

- Dioxins and Furans (polychlorinated dibenzodioxins [PCDD] and polychlorinated dibenzofurans [PCDF])
- Mercury (Hg)
- Semivolatile metals (cadmium and lead)
- Low volatility metals (antimony, arsenic, beryllium, and chromium)
- Total chlorine (considering both HCl and chlorine [Cl_2])
- CO
- PM

As proposed, the MACT rule would establish a floor standard based on the average performance of the best 12 percent of existing sources (as indicated by an EPA review of existing incinerators). EPA may elect to set more stringent, but technically achievable, beyond-the-floor standards for specific constituents, depending on an evaluation of the incremental additional benefits and costs of such an approach.

The proposed MACT rule governing HWC devices also would require the use of five continuous emissions monitors (CEM):

- CO
- THC
- Oxygen (O_2) (used for correction to 7 percent oxygen)
- Mercury (Hg)[1]
- PM

The proposed MACT rule governing HWC devices was published in the FR on April 19, 1996. Because of the complexity of the rule and the number of comments it elicited, EPA reevaluated the rule and issued revised proposed technical standards on May 2, 1997. At the time this report was published, the proposed rule had not yet become final. Table 5 shows current and proposed emissions standards that are potential ARARs for remedial actions that involve on-site incineration.

Analysis of the proposed standards indicates that all the incinerators that were evaluated would have met the proposed standards for particulate matter. The incinerators also would have met the standard for carbon monoxide (which is not proposed to change). Bridgeport was the only site that required monitoring for volatile and semivolatile metals; however, that incinerator would have been in compliance with the proposed standards.

Overall the cases studied met their treatment objectives. Problems when encountered were primarily of an operational nature. Although these problems slowed the incineration at these sites, they did not result in increased risks to the community.

[1] Although the use of Hg CEMs was proposed, it is not expected that EPA will require their use in the final MACT rule. In a recent Federal Register (FR) notice [62 FR 67788; December 30, 1997], EPA states "...As a result, the Agency now believes it has not sufficiently demonstrated the viability of Hg CEMs as a compliance tool at all hazardous waste combustors and should not require their use. Nonetheless, EPA still believes Hg CEMs can and will waste at some sources but does not have sufficient confidence that all HWC conditions are conducive to proper operation of the Hg CEMs tested..."

Table 1. General Information on the Selected Sites
(Page 1 of 5)

Site Name	Incineration System Design	Media (Quantity)	Principal Contaminants	Comments
Baird & McGuire, MA	Rotary kiln, SCC, quench tower, baghouse, wet scrubbing system	• Soil (210,000 tons) • Sediment (1,500 cubic yards)	• Dioxin • Volatile organic compounds (VOCs) • Polynuclear aromatic hydrocarbons (PAHs) • Pesticides	• Wide variety of contaminants.
Bayou Bonfouca, LA	Rotary kiln, SCC, quench system, gas conditioner, scrubber, mist eliminator	• Sediment (169,000 cubic yards)	• PAHs	• Volume of contaminated soil underestimated by a factor of three.
Bridgeport Refinery and Oil Services, NJ	Rotary kiln, SCC, cyclone separator, venturi quench, packed tower scrubber, mist eliminator	• Lagoon sediment and sludge (138,350 tons) • Debris (13,000 tons) • Levee material (12,550 tons) • Lagoon oil (3,850 tons) • Soil (4,250 tons)	• PCBs • VOCs	• Inadequate design caused numerous mechanical problems. • Incineration operation suspended twice because of mechanical problems. • Problems with demulsifying complicated dewatering of sediment.
Celanese Corporation Shelby Fiber Operations, NC	Rotary kiln, SCC, quench duct, baghouse, packed bed scrubber system	• Soil and sludge (4,660 tons)	• Ethylene glycol • VOCs • PAHs • Phenol	• Smallest amount incinerated among the case studies.

Table 1. General Information on the Selected Sites
(Page 2 of 5)

Site Name	Incineration System Design	Media (Quantity)	Principal Contaminants	Comments
Coal Creek, WA	Rotary kiln, SCC, baghouse, scrubber	• Soil (9,715 tons)	• PCBs	• Compliance with DRE requirements was allowed to be demonstrated without spiking, because of the previous performance of the incinerator, and because it had a TSCA permit.
FMC Corporation - Yakima, WA	Rotary kiln, SCC, quench tank, venturi scrubber, cooling tower, packed bed adsorber, ionizing wet scrubber	• Soil (5,600 cubic yards)	• Pesticides	• Frigid ambient air temperatures caused delays in setting up the incinerator, as shakedown activities occurred during the winter months (shakedown and testing originally had been scheduled for spring and summer).

Table 1. General Information on the Selected Sites
(Page 3 of 5)

Site Name	Incineration System Design	Media (Quantity)	Principal Contaminants	Comments
MOTCO, TX	Rotary kiln, SCC; second incinerator with single liquid injection combustion chamber; both had quench system, gas conditioner, wet scrubber, mist eliminator	• Soil (4,699 tons) • Sludge (283 tons) • Organic liquids (7,568 tons) • Aqueous waste (10,471 tons)	• Styrene tars • VOCs	• Mechanical problems, caused in part by the lack of accurate waste characterization, were encountered. • On-site incineration was stopped in December 1991 because of a dispute between the contractor and the responsible party tons incinerated. • Remedy was changed to off-site incineration, in part because of the dispute and mechanical problems.
Old Midland Products, AR	Rotary kiln, SCC, quench tower, venturi scrubber, baghouse, wet scrubber	• Soils, sludges, and sediments (102,000 tons)	• Pentachlorophenol • PAHs	• According to project managers, this incineration project encountered few problems because of good waste characterization.
Petro Processors, LA	Horizontal liquid injection incinerator, quench tank, wet scrubber, particulate scrubber, entrainment separator	• Organic liquids and fumes (213,376 gallons, as of June 1997)	• Chlorinated hydrocarbons • PAHs • Oils	• Incineration is used to treat free product and emissions from a groundwater pump and treat system. • Site personnel believe that the operation has been relatively trouble-free.

Table 1. General Information on the Selected Sites

Site Name	Incineration System Design	Media (Quantity)	Principal Contaminants	Comments
Rocky Mountain Arsenal, CO	Submerged quench incinerator, quench chamber, spray dryer, venturi scrubber, packed tower scrubber	• Liquids (10.9 million gallons)	• Organochloric and organophosphoric pesticides	• Innovative design was used to capture metal particulates. • Recovered enough copper to recycle.
Rose Disposal Pit, MA	Rotary kiln, SCC, cyclone separator, baghouse, quench towers, wet scrubbing system	• Soil (51,000 tons)	• PCBs • VOCs	• Incinerator used to treat more than 50,000 tons of soil contaminated with PCBs.
Rose Township Dump, MI	Infrared incinerator, SCC, quench, venturi scrubber, packed-column scrubber	• Soils, rocks, and tree stumps (34,000 tons)	• PCBs • VOCs • Semivolatile organic compounds (SVOCs)	• An estimated 600 tons of incinerator ash required reincineration because it did not meet requirements for on-site disposal.
Sikes Disposal Pits, TX	Rotary kiln, SCC, quench section, venturi, two-stage scrubber	• Soil and debris (496,000 tons) • Contaminated water (350 million gallons)	• Organic and phenolic compounds	• Two SCCs in parallel were required to maximize throughput of incinerator. • Steam generated by quenching of slag caused overpressurization in the kiln.

Table 1. General Information on the Selected Sites
(Page 5 of 5)

Site Name	Incineration System Design	Media (Quantity)	Principal Contaminants	Comments
Times Beach, MO	Rotary kiln, SCC, quench section, venturi, two-stage scrubber	• Soil and debris (265,000 tons)	• Dioxin	• The site served as a central treatment facility for 27 sites in the state of Missouri that were contaminated with dioxin. • A release of untreated kiln gases occurred when a storm interrupted power to the incinerator and blew out the pilot lights on the emergency relief vent system.
Vertac Chemical Corporation, AR	Rotary kiln, SCC, cyclone separators, wet scrubbers	• Still bottom waste and soil in drums (9,804 tons)	• Dioxin • VOCs • Pesticides	• In 1986, after several unsuccessful trial burns, the first contractor left the site and the RP declared bankruptcy. • Two temporary restraining orders were filed to stop the incineration project in light of public concern about the incineration of dioxin-listed waste; on-site incineration proceeded with non-dioxin wastes.

Table 2. Selected Stack Gas Emissions Measured During Trial Burn
(Page 1 of 2)

Site Name	Average DRE (%)	Stack Particulates (corrected to 7% oxygen)	Stack HCl (lb/hr)	Stack CO (60-minute rolling average, corrected to 7%oxygen)
Limit	**Greater than or equal to 99.99 for organic constituents Greater than or equal to 99.9999 for dioxin and PCB contaminated media**	**Not greater than 0.08 gr/dscf**	**Not greater than the larger of either 4lb/hr or 1% of the HCl in the stack gas prior to entering any APCD**	**Not greater than 100 ppmv**
Baird & McGuire, MA	99.99991	NA	NA	NA
Bayou Bonfouca, LA	99.99	0.0059	0.035	1 ppm
Bridgeport Refinery and Oil Services, NJ	99.99995	0.018	3.97	4,500 g/hr
Celanese Corporation, NC	99.9995	0.00359	<0.02575	2 ppm
Coal Creek, WA	99.99994	0.000532	0.0205	Below detection limit
FMC Corporation-Yakima Pit, WA	99.999992	0.0014	0.0088	18.44 ppm
MOTCO, TX	99.9999 for PCBs	0.052	0.045	0.0 ppm
Old Midland, AR	99.99987	0.0024	0.15	13.4 ppm
Petro Processors *, LA	99.999988	liquid mode: 0.0264 fume mode: 0.0018	liquid mode: 0.190 fume mode: 0.01	liquid mode: 1.7 ppm fume mode: 3.8 ppm
Rocky Mountain Arsenal, CO	99.9989	0.0214	0.2291	51.5 ppm
Rose Disposal Pit , MA	99.99987	NA	NA	9.9 ppm

Table 2. Selected Stack Gas Emissions Measured During Trial Burn
(Page 2 of 2)

Site Name	Average DRE (%)	Stack Particulates (corrected to 7% oxygen)	Stack HCl (lb/hr)	Stack CO (60-minute rolling average, corrected to 7% oxygen)
Rose Township Dump, MI	99.99982	NA	NA	3.34 ppm
Sikes Disposal Pits, TX	99.9996	0.0073	<0.027	1.0 ppm
Times Beach, MO	99.99998	0.014	0.014	0.0 ppm
Vertac Chemical Corporation, AR	99.99985	NA	NA	NA

* Incinerator is part of a groundwater treatment system that treats recovered liquid organic compounds and fumes from an air stripper.

Table 3. Selected Matrix Characteristics and Values for Operating Parameters (Page 1 of 2)

Site Name	Medium Classification	Moisture Content (%)	Stack Gas Flow During Trial Burn	Primary Combustion Chamber Residence Time During Trial Burn	System Throughput During Trial Burn	Kiln Temperature
Baird & McGuire, MA	Unclassified soil and sludge	9	44,435 acfm	NA	25 tons/hr	NA
Bayou Bonfouca, LA	Sediment	52	43,560 acfm	30-40 minutes	28.6 tons/hr	1,094°F
Bridgeport Refinery and Oil Services, NJ	Unclassified soil	NA	20,000 to 37,000 acfm	40-80 minutes	24 tons/hr	1,200°F to 1,600°F
Celanese Corporation, NC	Semiviscous sludge	25	1,750 feet per second	45 minutes	2.3 tons/hr	1,500°F
Coal Creek, WA	Unclassified soil	NA	15,074 acfm	30 minutes	10 tons/hr	1,700°F to 2,000°F
FMC Corporation-Yakima Pit, WA	Unclassified soil and debris	NA	NA	NA	NA	600°C to 1,000°C
MOTCO, TX	Unclassified soil and sludge	25 (varied feed)	42-117 acfm	15-90 minutes	12 tons/hr (solid) 512 lbs/hr (quench liquid) 825 lbs/hr (organic liquid)	950°F
Old Midland, AR	Unclassified soil and sludge	~40 (sludge) ~15 (soil)	12,500 dscf	NA	18 tons/hr	1,200°F to 1,800°F
Petro Processors, LA	Liquid	Not Applicable	NA	2 seconds	0.735 tons/hr (liquid mode)	1,600°F (fume mode) 2,000°F to 2,300°F (liquid mode)

Table 3. Selected Matrix Characteristics and Values for Operating Parameters (Page 2 of 2)

Site Name	Medium Classification	Moisture Content (%)	Stack Gas Flow During Trial Burn	Primary Combustion Chamber Residence Time During Trial Burn	System Throughput During Trial Burn	Kiln Temperature
Rocky Mountain Arsenal, CO	Liquid	Not Applicable	438 scfm	2 seconds	176 lbs/min	1,750°F to 1,900°F
Rose Disposal Pit, MA	Sand, silt, and clay	NA	NA	NA	50 tons/hr	NA
Rose Township Dump, MI	Unclassified soil	13.1 to 14.2	NA	10-60 minutes	6.9 tons/hr	1,400°F to 1,800°F
Sikes Disposal Pits, TX	Unclassified soil, debris	10 to 12	47,550 acfm	45 minutes	46 tons/hr	1,236°F
Times Beach, MO	Unclassified soil, debris	7.8	38,300 acfm	60 minutes	31 tons/hr	1,250°F
Vertac Chemical Corporation, AR	Still bottom waste in drums	Not Applicable	NA	40 minutes	NA	2,000°F

Table 4. Summary of Cost Data for Each Site
(Page 1 of 3)

Site Name	Project Cost: Treatment	Project Cost: Total	Quantity Incinerated	Calculated Unit Cost for Treatment**	Total Unit Cost	Comments
Baird & McGuire, MA	NA	$133,000,000	248,000 tons of soil and sediment	NA	$540/ton	• No comments.
Bayou Bonfouca, LA	$72,000,000	$110,000,000	250,000 tons of sediment and waste pile material	$288/ton	$440/ton	• EPA paid for the incineration on the basis of dry weight of the ash instead of the weight of the feed material. It therefore was more desirable to the contractor to optimize the process train and guard against the unnecessary incineration of moisture.
Bridgeport Refinery and Oil Services, NJ	NA	NA	172,000 tons of sediment, sludge, debris, oil, and soil	NA	NA	• SCC supports required rebuilding to repair loss of structural integrity. • Slag falling into ash quench caused damage to ash and feed augers requiring numerous repairs.
Celanese Corporation, NC	$1,900,000	$5,300,000	4,660 tons of soil and sludge	$410/ton	$1,000/ton	• The site operator believes on-site incineration was uneconomical, compared with off-site incineration because a relatively small amount of waste was treated.
Coal Creek, WA	NA	$8,100,000	9,715 tons of soil	NA	$830/ton	• No comments.
FMC Corporation-Yakima Pit, WA	NA	$6,000,000	7,840 tons of soil*	NA	$770/ton	• Statistical methodology used to minimize the amount of soil excavated.

Table 4. Summary of Cost Data for Each Site
(Page 2 of 3)

Site Name	Project Cost: Treatment	Project Cost: Total	Quantity Incinerated	Calculated Unit Cost for Treatment**	Total Unit Cost	Comments
MOTCO, TX	$31,000,000	$76,000,000	23,021 tons of soil, sludge, organic liquid, and aqueous waste	$1,350/ton	$3,300/ton	• Inaccurate initial characterization of the waste stream resulted in many mechanical problems during incineration operation.
Old Midland, AR	$22,500,000 (excavate, incinerate, backfill)	$27,000,000	102,000 tons of soil, sludge, and sediment	$220/ton (excavate, incinerate, backfill)	$264/ton	• The criterion for dioxin and furans in ash was raised from 0.1 to 1.0 ppb, reducing residence time and increasing throughput. • Amount of contaminated soil underestimated.
Petro Processors, LA	$4,800,000 (to date)	$32,800,000 (to date)	213,000 gallons of organic liquid and fumes (to date)	$21/gal	$154/gal	• No comments.
Rocky Mountain Arsenal, CO	$58,100,000	$93,000,000	10.9 million gallons of liquid	$5/gal	$9/gal	• Heavy rainfall increased volume of liquid requiring treatment. The construction of a special holding pond was required, increasing "before treatment" capital costs. • Before treatment costs were $14,800,000; after treatment costs were $18,900,000.
Rose Disposal Pit, MA	NA	NA	51,000 tons of soil	NA	NA	• Operating in the winter caused weather-related difficulties, resulting in suspension of the operation until spring.

Table 4. Summary of Cost Data for Each Site
(Page 3 of 3)

Site Name	Project Cost		Quantity Incinerated	Calculated Unit Cost for Treatment**	Total Unit Cost	Comments
	Treatment	Total				
Rose Township Dump, MI	NA	$12,000,000	34,000 tons of soil, rocks, and tree stumps	NA	$350/ton	• An estimated 600 tons of incinerator ash required reincineration because it did not meet criteria for on-site disposal.
Sikes Disposal Pits, TX	$81,000,000	$115,000,000 (total includes $11,000,000 in miscellaneous O&M costs)	496,000 tons of soil and debris	$160/ton	$230/ton	• Completed 18 months ahead of schedule because the contractor supplied a larger incinerator. • Before treatment costs were $20,000,000; after treatment costs were $3,000,000.
Times Beach, MO	Confidential	$110,000,000	265,000 tons of soil and debris	Confidential	$420/ton	• An estimated 1,900 tons of incinerator ash required reincineration because it did not meet criteria for backfilling.
Vertac Chemical Corporation, AR	NA	$31,700,000	9,804 tons waste and soil	NA	$3,200/ton	• The mixed solid and liquid waste stream had a variable Btu content, creating difficulties in maintaining optimal temperature in the kiln. • Because of low pH of waste stream issues related to worker health and safety arose. • Residual ash was disposed of in a facility permitted under RCRA Subtitle C, thereby increasing disposal costs.

* Quantity reported as cubic yards. Tons were calculated by multiplying cubic yards by an average density value of 1.4.
** Unit cost calculated when costs for treatment only were available; does not include costs for before-treatment or after-treatment.

Table 5. Current and Proposed Incinerator Standards

Pollutant	RCRA Current Standards Under Parts 264/265 Subpart O	April 16, 1996 Proposed MACT Standards	May 2, 1997 Revised MACT Standards
Dioxins/furans (ng TEQ/dscm)	No Federal emissions standard[2]	0.2	0.2
Mercury (μg/dscm)	No Federal emissions standard[3]	50	40
Total chlorine (HCl and Cl_2) (ppmv)	No greater than 4 lb/hr or 1% HCl in stack gas prior to entering any pollution control equipment	280	75
Semivolatile metals (lead, cadmium) (μg/dscm)	No Federal emissions standard[3]	270	100
Low volatility metals[1] (antimony, arsenic, beryllium, chromium) (μg/dscm)	No Federal emissions standard[3]	210	55
Particulate matter (gr/dscf)	0.08	0.03	0.015
Carbon monoxide (ppmv)	100	100	100
Total hydrocarbons (ppmv)	No Federal emissions standard	12	10

dscf: Dry standard cubic feet
dscm: Dry standard cubic meters
gr: Grains
ppmv: Parts per million by volume
TEQ: Toxic equivalents
μg: Micrograms
ng: Nanograms

1 EPA has determined that emissions on antimony may be adequately addressed by meeting the particulate matter standard.

2 Dioxin/furan limits may be imposed based on results of site-specific risk assessments under the RCRA omnibus authority (40 CFR 270.32(b)(2)).

3 RCRA permitting authority may be used to impose BIF metal limits (40 CFR 266.106) or limits based on site-specific risk assessment results (40 CFR 270.32(b)(2)).

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4. EPA. Technical Support Document for HWC MACT Standards, Volume 1: Description of Source Categories. Draft. RCSP-S0047. February 1996.

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